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ALBEDO AND EARTH RADIATION DEDUCED FROM EMISSIVITY SENSORS ON THE FIRST ORBITING SOLAR OBSERVATORY

By J. P. Millard and C. B. Neel

NASA, Ames Research Center, Moffett Field, Calif

SUMMARY

The emissivity experiment on the first Orbiting Solar Observatory yields, as part of the data on the stability of temperature-control coatings in space, information on earth-reflected sunlight and earth-emitted energy. Localized values of both albedo and earth radiation deduced from these data are presented.

Descriptions of the experiment and radiometric technique, a comparison of the resultant values with other reported data, and an analysis of possible error associated with the results are included. The implications of the results of this analysis to the reporting of radiometric data areoalso discussed.

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INTRODUCTION

Knowledge of the quantity of radiant energy reflected and emitted from the earth and its atmosphere is required, not only in analysis of the heat budget of the earth for meteorological purposes, but also in calculations of the heating of near-earth satellites. Until recently, values of earth- reflected solar energy, or albedo, and earth-emitted infrared radiation, for example, those reported in references 1, 2, and 3, have, of necessity, been deduced indirectly from observations made from within the Earth-Atmosphere System. With the advent of scientific satellites, direct measurement of these quantities from outside the atmosphere has been made possible. The greatest amount of information has been obtained from the Tiros series of meteorological satellites, which carried equipment designed specifically for measuring reflected and emitted radiation. Descriptions and results of these experiments are contained in references 4 and 5.

Results from an experiment on the first Orbiting Solar Observatory also have given data on the intensity of reflected sunlight and earth radiation. Although this experiment, as described in references 6 and 7, was designed for another purpose (dash) – that of determining the long-term stability of radiation properties of several thermal-control coatings (dash) – deductions of albedo and earth radiation have been made from the measurements. ~~are limited both in quantity and scope.~~ These values of albedo and earth radiation are limited both in quanity and scope. Nevertheless, they are considered ~~to be~~ sufficiently valuable as a supplement to previous measurements to warrant reporting. In the process of reducing the data, an error analysis, which is believed to have general application in radiometric measurements of this type, was performed. The analysis

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illustrates the large uncertainties that may exist in ~~determining~~ albedo and earth radiation values deduced ~~which can result~~ from radiometric measurements.

This paper presents the results obtained from the OSO-I experiment and gives comparisons with previous measurements of albedo and earth radiation. The uncertainty analysis for the present data is given, and implications of the results are discussed in reference to other radiometer measurements of albedo and earth radiation.

ratio of earth-reflected to incident solar energy

SYMBOLS

A	area of sensor surface, ft^2
a	albedo,
c	specific heat of sensor, BTU/lb°R
E	earth-emitted radiant flux, BTU/hr ft^2
F_A	albedo view factor, defined by $H_A = SaF_A$
F_E	Earth view factor, defined by $H_E = F_E E$
H_A	earth-reflected solar flux, incident on sensor surface, BTU/hr ft^2
H_E	earth-emitted radiant flux incident on sensor surface, BTU/hr ft^2
H_S	direct solar flux incident on sensor surface, BTU/hr ft^2
K	heat exchange constant for sensor mount, BTU/hr °R^4
Q_K	net heat flux incident upon sensor due to imperfect thermal isolation, equal to $K(T_b^4 - T^4)$
S	solar constant, taken as 442 BTU/hr ft^2
T	temperature of sensor, °R
T_b	temperature of sensor mounting cup, °R
V	a function of n independent variables
w	mass of sensor disk, lb.
x_i	independent variable
α_A	albedo-radiation absorptance of sensor surface
α_E	earth-radiation absorptance of sensor surface
α_S	solar-radiation absorptance of sensor surface
ϵ	infrared emittance of sensor surface
θ	time, hr
σ	Stefan-Boltzmann constant, 0.1714×10^{-8} BTU/hr $ft^2 R^4$

ANALYSIS OF RADIOMETRIC TECHNIQUE

A radiometer is an instrument for measuring electromagnetic radiation. The measurement is an indirect one in the sense that quantitites which show the effect of radiation, such as the temperature rise of a calorimeter or the torsional twist of a suspended disk, blackened on one side, are the measured quantities. From data such as these, the magnitude of energy absorbed by the detector can be determined. If in addition the intensity distribution of radiant energy ~~radiating object~~ is known or assumed, ~~to radiate in a prescribed manner,~~ the total energy emitted by ~~that~~ an object can be deduced. Of particular interest are the calorimetric-type measurements such as those employed on the first Orbiting Solar Observatory. Albedo and earth radiation were deduced from time-temperature histories of two isolated surfaces in space. [~~and the assumption that the earth-atmosphere system emits and reflects according to a cosine distribution.~~]

Heat Balance Equations

[~~The applicable radiometric equation for calorimetric-type measurements is that of an energy balance.~~] Consider the energy balance on a thin flat plate, thermally isolated on its back side, located many miles above the earth, and oriented in such a manner as to see at least a portion of it. The ~~thin plate, or~~ surface of the plate will intercept direct energy from the sun, and energy emitted and reflected by the earth. The equation of energy balance of the surface is:

$$H_S A\alpha_S + H_A A\alpha_A + H_E A\alpha_E + Q_K = A\epsilon\sigma T^4 + wc\frac{dT}{d\theta} \qquad (1)$$

The terms on the left side of the equation are the above mentioned heat inputs from the earth and sun plus the energy term Q_K which represents that due to imperfect thermal isolation on the back side. The terms on the right represent the radiant emission and thermal capacitance of the surface.

The heat-input parameters H_S, H_A, and H_E are functions of the intensity distribution of emitted and reflected radiation, and the orientation of the surface with respect to sun and earth. The relative amount of energy emitted or reflected by the sun or earth that is incident upon the surface is described by the term "view factor." The heat-input parameters are related to the heat sources and view factors by the following equations:

$$H_S = F_S S \tag{2}$$

$$H_A = F_A \alpha S \tag{3}$$

$$H_E = F_E E \tag{4}$$

where F_S, F_A, and F_E are the solar, albedo, and earth radiation view factors. Substitution of equations (2), (3), and (4) into equation (1) results in an equation in terms of S, A, and E. To determine albedo and earth radiation, one or more such equations must be solved for the terms α ~~A~~ and E. The procedures used in the solution of these terms will be discussed presently.

In the subsequent analysis, the following assumptions were made: (1) the value of albedo-radiation absorptance of the radiometer surface, α_A, was assumed to equal the value of solar-radiation absorptance α_S; (2) the infrared absorptance, α_S, of the surface was taken equal to the infrared emittance, ϵ; (3) the earth was assumed to emit and reflect according to a cosine distribution; (4) the heat input term, Q_K, which represents heat input to the sensor from its back side was set equal to $K(T_b^4 - T^4)$, where K is a proportionality factor, T is the temperature of the radiometer surface, and T_b is the temperature of the object behind the surface with which it exchanges heat.

Earth radiation determination.- Earth radiation can be deduced from data recorded on either day or night portions of an orbit. Values ~~can be~~ are obtain~~ed~~able in one of two ways: (1) solution of a single energy equation, or (2) simultaneous solution of energy equations for two different radiometer surfaces. If the single energy equation and sunlit-side data are employed, a value of albedo must be assumed. If dark-side data are used, the assumption is unnecessary since the solar and albedo terms are zero.

The equation for determination of earth emission, derived from the single energy equation, equation 1, plus the relationships of equations (2), (3), and (4), is:

$$E = \frac{1}{F_E}\left[\sigma T^4 - \frac{\alpha_S}{\epsilon}\left(F_S S + F_A \rho S\right) + \frac{wc}{\epsilon A}\frac{dT}{d} + \frac{K}{\epsilon A}\left(T^4 - T_b^{\,4}\right)\right] \tag{5}$$

Considering the simultaneous solution of the energy equations for two radiometer surfaces exposed to the sunlit side of the earth, the earth-emitted energy can be written :

$$E = \frac{1}{F_E\left(\left.\frac{\epsilon}{\alpha}\right|_1 - \left.\frac{\epsilon}{\alpha}\right|_2\right)}\left[\begin{array}{l}\left.\frac{\epsilon}{\alpha_S}\right|_1 \sigma T_1^{\,4} - \left.\frac{\epsilon}{\alpha_S}\right|_2 \sigma T_2^{\,4} - \left.\frac{wc}{A\alpha_S}\right|_2 \left.\frac{dT}{d\theta}\right|_2 - \left.\frac{K}{A\alpha_S}\right|_2 \left(T_2^{\,4} - T_b^{\,4}\right) \\ + \left.\frac{wc}{A\alpha_S}\right|_1 \left.\frac{dt}{d\theta}\right|_1 + \left.\frac{K}{A\alpha_S}\right|_1 \left(T_1^{\,4} - T_b^{\,4}\right)\end{array}\right] \tag{6}$$

where the subscripts 1 and 2 refer to the two radiometer surfaces. In the application of this equation, if the α_S/ϵ ratios of the two surfaces are nearly the same, a small error in one will result in a large uncertainty in E. It is therefore desirable to employ surfaces which have distinctively different α_S/ϵ ratios.

Albedo determination.- Albedo values must be deduced from data recorded only on the sunlit portion of an orbit, since the dark side of the earth receives no solar energy to reflect. The solution of a single energy equation, in which a value of earth radiation has been assumed, or the simultaneous solution of two energy equations will yield the desired results.

Values of albedo can be derived by solution of the following single energy equation:

$$a = \frac{1}{442\ F_A}\left[\frac{\epsilon}{\alpha_S}\left(\sigma T^4 - EF_E\right) - F_S S + \frac{wc}{A\alpha_S}\frac{dt}{d\theta} + \frac{K}{A\alpha_S}\left(T^4 - T_b{}^4\right)\right] \tag{7}$$

And the simultaneous solution of two energy equations can be written:

$$a = \frac{1}{442\ F_A\left(\left.\frac{\alpha_S}{\epsilon}\right|_1 - \left.\frac{\alpha_S}{\epsilon}\right|_2\right)}\left[\begin{array}{l}\sigma T_1{}^4 - \sigma T_2{}^4 - \left(\left.\frac{\alpha_S}{\epsilon}\right|_1 - \left.\frac{\alpha_S}{\epsilon}\right|_2\right) F_S S + \left.\frac{wc}{\epsilon A}\right|_1\left.\frac{dT}{d\theta}\right|_1 \\ - \left.\frac{wc}{\epsilon A}\right|_2\left.\frac{dt}{d\theta}\right|_2 + \left.\frac{K}{\epsilon A}\right|_1\left(T_1{}^4 - T_b{}^4\right) - \left.\frac{K}{\epsilon A}\right|_2\left(T_2{}^4 - T_b{}^4\right)\end{array}\right] \tag{8}$$

As in the case of deduction of earth radiation, large uncertainties can result in the solution of equation (8) if the α_S/ϵ ratios of the two radiometer surfaces have nearly the same value, and again, surfaces having distinctively different α_S/ϵ ratios should be utilized.

Uncertainty Analysis

All experimental measurements are subject to some degree of error. When these data are used to deduce other quantities, the resultants will have corresponding uncertainties. ~~In order to make use of~~ If these quantities are to be useful, a measure of their reliability must be provided. Specifically, albedo and earth radiation can be deduced from experimentally measured values of temperature, optical properties, etc. These values may be accurately measured, but all are subject to some degree of error. The question is, what is the associated error in albedo and earth radiation due to the propagation of the uncertainty of the individual terms from which they are deduced?

The uncertainties in albedo and earth-radiation were computed by the method of Kline and McClintock as described in references 8 and 9. They define uncertainty as "a possible value the error might have." The method of analysis will follow. If the quantity V is a function of n independent variables, $x_1, x_2 \dots x_n$, then for small changes in these variables, the proportional change in V can be expressed as:

$$\Delta V = \sqrt{\frac{\partial V}{\partial x_1}\Delta x_1 + \frac{\partial V}{\partial x_2}\Delta x_2 + \dots + \frac{\partial V}{\partial x_n}\Delta x_n} \qquad \text{9 } (11)$$

Let x_i represent the uncertainty of each independent variable. If, in addition to being small, the uncertainties are independent and equally probable, and if the variables are estimated to fall within their uncertainty interval with odds of, say, 10:1, then V will fall within the interval $V \pm \Delta V$ with the same odds when ΔV is defined by:

$$\Delta V = \sqrt{\left(\frac{\partial V}{\partial x_1}\Delta x_1\right)^2 + \left(\frac{\partial V}{\partial x_2}\Delta x_2\right)^2 + \dots + \left(\frac{\partial V}{\partial x_n}\Delta x_n\right)^2} \qquad \text{10 } \cancel{(12)}$$

The uncertainty interval of each variable should be determined by an analysis of the method by which it was obtained. Often, however, it is too time consuming, inconvenient, or even impossible to conduct a complete analysis. In general, an educated guess may be better than none at all. The values to be employed are not necessarily extremes, but those within which the error should fall with reasonable odds. ~~of, say, 10:1.~~

Earth radiation.- Specific application of the method of Kline and McClintock will be made to the determination of the uncertainty of deduced values of earth radiation. The energy equation, equation 5, ~~relating to the dark portion of the orbit~~ can be written:

$$E \quad f(T, \frac{dT}{d\theta}, T_b, \alpha_S/\epsilon, \epsilon, A, S, a, wc, K, F_E) \tag{11}$$

The uncertainty of deduced values of E is described by:

$$\Delta E = \sqrt{\left(\frac{\partial E}{\partial T}\Delta T\right)^2 + \left(\frac{\partial E}{\partial \frac{dT}{d\theta}} \Delta \frac{dT}{d\theta}\right)^2 + \ldots + \left(\frac{\partial E}{\partial F_E}\Delta F_E\right)^2} \tag{12}$$

Albedo.- Analogously, the uncertainty of deduced values of albedo may be determined. However, in this case, all variables are not independent. The energy equation, eq. 7, can be written:

$$a = f(T, \frac{dT}{d\theta}, T_b, \alpha_S/\epsilon, \alpha_S, A, S, E, wc, K, F_s, F_E, F_A) \tag{13}$$

The view factors F_E and F_A are not independent. Both are a function of the geometrical area of the earth viewed by the sensors. For every error associated with the determination of F_E, there will be a corresponding error associated with F_A. Both errors will be in the same direction; that is, a simultaneous increase or decrease of both values. Providing α_S/ϵ and α_S are obtained from independent measurements, all remaining terms may be considered to be independent. The uncertainty equation for this case can be written:

$$\Delta a = \sqrt{\left(\frac{\partial a}{\partial T}\Delta T\right)^2 + \left(\frac{\partial a}{\partial \frac{dT}{d}} \Delta \frac{dT}{d\theta}\right)^2 + \ldots + \left(\frac{\partial a}{\partial K}\Delta K\right)^2 + \left(\frac{\partial a}{\partial F_E}\Delta F_E + \frac{\partial a}{\partial F_A}\Delta F_A\right)^2} \tag{14}$$

DESCRIPTION OF EXPERIMENT

The Emissivity Experiment on the first Orbiting Solar Observatory consisted of a cluster of temperature-control surfaces thermally isolated from each other and the spacecraft, and a means of recording their temperatures. ~~Those surfaces whose optical and thermal properties were accurately known were used independently as radiometers.~~ Features of the experiment pertinent to the determination of albedo and earth radiation will be discussed.

Sensor Design

Each radiation sensor consisted of a surface, or coating, applied to a metallic substrate to which a thermistor was attached on the underside for temperature measurement. In order to minimize extraneous heat losses, each was mounted in a specially designed mounting cup as shown in figure 1.

Test Surfaces

Seven surfaces were employed as part of the Emissivity Experiment. One of these was a reference surface designed to remain optically stable in the space environment. It was composed of razor-blades, with blackened finish, stacked together, as shown in figure 2, to form a series of small apex-angle vee grooves. Hence, most incident radiation experienced multiple reflections and eventual absorption. As a result, the reference surface was a good approximation of a black body. Because of the design, any change in the emittance or reflectance of the local surface would have had only a small effect on the over-all emittance or absorptance of the reference surface. A complete list of the surfaces employed as part of the emissivity experiment follows.

1. Razor-blade reference
2. Aluminum powder in silicone
3. TiO_2 in epoxy
4. TiO_2 in silicone

5. White porcelain enamel

6. Al-SiO-Ge

7. Al-SiO-Ge-SiO

~~were considered~~

Of these surfaces, only two appeared to be worth considering as radiometer-detector-surfaces for the determination of albedo. Those are the razor-blade reference and the aluminum powder in silicone ~~TiO_2 in epoxy~~. This selection resulted from the requirement that the optical properties be known with good accuracy. Since infrared absorptance of the surfaces was not measured, it was necessary that infrared emittance be independent of wavelength so that infrared absorptance could be adequately inferred. Both surfaces met this requirement. Since the flight-deduced values of α_S/ϵ and the laboratory-measured values ~~of~~ α_S (refs. 6, 7) were considered the best available data, it was necessary, in order to use ~~that~~ these data ~~be used~~ simultaneously in an energy equation, that each surface be stable in space. Both met this requirement. However, Due to the fact that the α_{SA}/ϵ ratios of the surfaces were nearly identical, the energy equations of the two surfaces were not solved simultaneously for albedo. Instead, the energy equation of a single surface was solved. The surface selected was the razor-blade reference, which has a solar absorptance of 0.97 and an α_S/ϵ ratio equal to 0.98. Besides its inherent stability, its solar absorptance is, for practical purposes, independent of angle of incidence.

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For analogous reasons plus the results of an uncertainty analysis ~~conducted on the data from the various surfaces~~, the TiO_2 in epoxy was selected to be the radiometer-detector-surface for earth-radiation. The infrared emittance of this surface, which is 0.85, may be considered stable in space (ref. 10). However, its solar absorptance is not. Accordingly, the surface was employed as a detector only in the dark portion of the orbits.

OSO Satellite

The Emissivity Experiment was mounted on the first Orbiting Solar Observatory which was launched March 7, 1962. The orbit, which was approximately

350 statute miles above the earth and inclined about 33° with respect to the equator, is illustrated in figure 3. Its period was 96 minutes.

The satellite is composed of two main parts, as shown in figure 4: A nine-sided-wheel lower section which rotates at 30 rpm, and a stabilized semicircular upper section aimed at the sun. The spin-axis of the rotating section was always maintained perpendicular to the satellite-sun line. However, the axis was free to rotate about this line. Its position, which was determined from satellite instrumentation, is known for only about the first two months in orbit. The Emissivity Experiment was mounted on the periphery of the rotating wheel/section, thereby viewing not only the earth, but alternately looking at the sun.

Data Acquisition

Experimental data were obtained only when the OSO was over the vicinity of the minitrack stations located in the north-south picket line from the southeastern coast of North America south along the west coast of South America. The data were received for about five minutes each orbit. The field of view of the radiation sensors is illustrated in figure 5. Because knowledge of the spin axis orientation is ~~essential to~~ necessary for the determination of albedo and earth radiation heat flux, only the time period for which this is known will be considered. As mentioned above, this is a period of approximately two months.

REQUIREMENTS FOR QUALIFICATION OF TEST SURFACES AS RADIOMETERS

Because none of the test surfaces included in the Emissivity Experiment were specifically designed to be radiometric sensor surfaces, it was necessary to determine which of them best qualified for such use. All surfaces were considered from the standpoint of usefulness in providing data on both ~~the sunlit~~ day and night sides of the orbit.

The primary requirement for qualification of a surface was that its optical properties be known with good accuracy. Flight-deduced values of α_S/ϵ, as described in references 6 and 7, were considered to be more accurate than those obtained by separate laboratory measurements ~~of the individual values~~ of α_S and ϵ. Additionally, laboratory measurements of the individual values of α_S and ϵ were considered more accurate than those deduced from flight data. Surfaces were selected as a result of the following considerations:

1. The most accurate values of the optical properties were known for those surfaces which possessed stable radiation characteristics. Hence, only stable surfaces were considered.
2. Since the earth radiation received by each sensor did not come from a source having the same temperature as the sensors, it follows that infrared absorptance was not necessarily equal to infrared emittance. Only surfaces having infrared emittance independent of wavelength, and consequently α_E equal to ϵ, were considered.

As a result of these considerations, only three surfaces qualified for use in the radiometric determinations. Two of these were for use on the ~~lighted~~ sunlit side of the orbit, and the other for use on the dark side.

The two which could have been utilized for the simultaneous solution of both albedo and earth radiation had α_S/ϵ ratios nearly equal. Since this would have lead to excessively large errors, the simultaneous-solution method was not used. Consequently, the surfaces were selected on the basis of their applicability to the solution of a single energy equation for albedo or earth radiation.

For measurement of earth radiation, the single energy equation, utilizing night side data, required that only the emittance, ϵ, be stable and independent of wavelength. Also, no assumption of albedo was necessary. The surface selected for this measurement was the TiO_2 in epoxy. Although the solar absorptance of this coating was found to be unstable, its infrared emittance is known through laboratory studies (ref. 10) to remain constant on exposure to simulated space environments. In addition, its emittance is independent of wavelength for the spectral region of interest. The measured value of ϵ is 0.85.

The surface selected as the radiometric sensor surface for determination of albedo was the razor-blade reference. Besides inherent stability and independence of emittance with wavelength in the infrared region, laboratory studies (ref. 7) indicate that its solar absorptance is independent of angle of incidence. The α_S/ϵ ratio of this surface, deduced from flight data (ref. 7), is 0.98, and the laboratory measured value of α_S is 0.97.

RESULTS AND DISCUSSION

Experimental data from the Emissivity Experiment on the first Orbiting Solar Observatory were utilized to deduce values of earth radiation and albedo. The reliability of these values was investigated by means of an uncertainty analysis. The results of the analysis are significant not only in the evaluation of present data, but also in application to satellite radiometric measurements in general. These results, plus comparative data from other satellite measurements, are presented in the following sections.

Earth Radiation

<u>OSO results</u>.- Application of experimental data from the TiO_2 in epoxy surface to the radiometric equation solved for E, equation 5, produced values of earth radiation. Only night-side data, which required no assumption as to the magnitude of the albedo term, were employed. The deduced values are presented graphically in figure 6, and in the following table as a function of date, and latitude, longitude and Minitrack Station near which the satellite was located at the times of data acquisition.

Date	Minitrack Station	Latitude of OSO	Longitude of OSO	Earth-Radiation Btu/hr ft^2	Equivalent Blackbody Temperature °R
March 11, 1962	Lima, Peru	-17.~~[illegible]~~	-78.~~[illegible]~~	101	493
March 23, 1962	Ft. Myers, Fla.	17.~~[illegible]~~	-84	109	502
April 3, 1962	Ft. Myers, Fla.	25	-85	106	499
April 5, 1962	Ft. Myers, Fla.	21	-89.~~[illegible]~~	93	483
May 3, 1962	Lima, Peru	1 ~~0.7599~~	-81.~~[illegible]~~	112	506
May 15, 1962	Ft. Myers, Fla.	29	-85	106	499
May 15, 1962	Ft. Myers, Fla.	33	-85	92	481

Uncertainty analysis.- The accuracy of the deduced results was determined by the application of equation (12) to the measured data. Uncertainty intervals within which the individual variables are believed to fall, with odds of approximately 10:1, are tabulated in Table I. As a result of the analysis, the reported values of earth radiation are believed to be within $\pm$ 9 Btu/hr ft^2 of the true values. The order of magnitude of the uncertainty was not found to be due to any particular term, but to the several uncertainties involved. However, better overall accuracy could be obtained if particular terms were known with more accuracy; primarily, these include infrared emittance, temperature, and change of temperature with time.

Comparative data.- To provide a comparison for the OSO results, data from Tiros III and IV will be presented. These data were reported by Suomi and House at the XIII General Assembly of the International Union of Geodesy and Geophysics held in Berkeley, California, August 1963, and Nordberg and Bandeen (ref. 5). The data presented by Suomi and House are presently unpublished. These particular sets of data were chosen because they were deduced from wide-field radiometers such as that flown on the OSO.

The data reported by Suomi and House were obtained from Tiros IV radiometric measurements made in the months of February, March, and April 1962. Their data were latitudinal averages; no data were presented for more specific geographical locations. The average values for the latitudes at which OSO results were given ranged from 74 to 84 Btu/hr ft^2. This is to be compared with OSO results ranging from 92 to 112 Btu/hr ft^2.

The OSO results, although larger than the latitudinal averages measured by Suomi and House, appear reasonable in light of data reported by Nordberg and Bandeen. Their data pertains to results from the Tiros III meteorological satellite. It should be mentioned that the field of view of the Tiros III wide-field radiometer is considerably smaller than that of the OSO sensors. The data of interest were obtained over geographical areas similar to those seen by OSO at the times of data acquisition. Nordberg and Bandeen present values of apparent earth blackbody temperature deduced from radiometric measurements made over the tropical Atlantic ocean in July, 1961. With the exception of some minor scattered clouds, the sky was clear at the times of these measurements. The blackbody temperatures were as high as 479° R. Due to the time constant of the instrument, the values were increasing, and it appears that larger values than this may be interpreted from the data. The emission of a 479° R blackbody is 90 Btu/hr ft^2. This value compares favorably with the OSO results of from 92 to 112 Btu/hr ft^2.

The commonly accepted value of the average global earth-radiation is approximately 72 Btu/hr ft^2. The origin of this value stems from calculations based on indirect measurements made prior to the advent of space satellites. Although considerably lower than the OSO results, it in no way denies the existence of larger or smaller values at more localized geographical regions.

Albedo

OSO results.- Equation (7) together with experimental data from the razor-blade reference surface were utilized to deduce values of albedo. Because solution of the equation requires knowledge or the assumption of earth radiation, E, the average (103 Btu/hr ft^2) of the previously deduced values was employed. The deduced values of albedo are presented in the following table as a function of date, latitude, longitude and Minitrack Station near which the satellite was located at the times of data acquisition.

Date	Minitrack Station	Latitude of OSO	Longitude of OSO	Albedo Values, %
March 8, 1962	Quito, Ecuador	-6	-75	23
" 9, 1962	"	5	-74	26
" 10, 1962	Ft. Myers, Florida	23	-86	12
" 11, 1962	Quito, Ecuador	-2	-78	23
" 11, 1962	Antofagasta, Chile	-22	-69	20
" 12, 1962	Quito, Ecuador	- 5	-81	23
" 12, 1962	Antofagasta, Chile	-24	-71	27
" 13, 1962	Lima, Peru	-10	-80	17
" 13, 1962	Antofagasta, Chile	-27	-71	28
" 19, 1962	"	-23	-73	38
April 3, 1962	"	-26	-67	34
" 16, 1962	Ft. Myers, Florida	-27	-88	23
" 16, 1962	"	32	-83	20
" 19, 1962	"	32	-84	25
" 21, 1962	"	30	-87	10
" 23, 1962	"	25	-82	19
May 3, 1962	Quito, Ecuador	- 1	-82	20

Uncertainty analysis.- As a result of the application of equation ~~13~~ 14 to the experimental data, it is believed~~, with odds of 10:1,~~ that the reported values of albedo are within approximately ± 0.10 of their true values. For a reported value of 20 percent, this amounts to ± 50 percent of its magnitude. Values employed for the uncertainty of individual variables, based on odds of approximately 10:1, are tabulated in Table ~~4~~ II. As with the earth-radiation data, the ~~order of~~ magnitude of the uncertainty was not found to be due to any particular term, but ~~of~~ to the many terms, ~~twelve all total,~~ thirteen involved. The effect of assuming a value of earth-radiation, with its corresponding uncertainty, was small, $\frac{\partial a}{\partial E} \Delta E$ being approximately 3 percent or less. It is also interesting to note that an uncertainty analysis conducted on the simultaneous solution of the energy equations of various combinations of the surfaces flown on the OSO experiment showed no better accuracy than that resulting from the single-energy equation.

Comparative data.- The Tiros IV results reported by Suomi and House were latitudinal averages. Their albedo values for the latitudes at which OSO results were obtained ranged from approximately 25 to ~~37~~ 34 percent. These are to be compared with the OSO results ~~just presented~~ given in the above table of ~~from~~ 10 to 38 percent.

The Tiros III results, reported by Nordberg and Bandeen, which pertain to the tropical Atlantic Ocean, are about 9 percent. As previously described, ~~the~~ these measurements were made over water, and the sky was clear at the times of these measurements. The field of view of the Tiros III wide-field radiometer was considerably smaller than that of the OSO radiometer. The Tiros III radiometer, at the times of the above measurements, viewed only water. Since the OSO radiometer viewed both land and water masses, and the sky was not necessarily free of clouds at the times of measurement, it is ~~to be expected~~ reasonable that the OSO results would be larger than 9 percent.

CONCLUDING REMARKS

Values of earth radiation and albedo were derived from an experiment on the first Orbiting Solar Observatory. The values were compared with results obtained from measurements on Tiros satellites. Although the Tiros results are not directly comparable either as to time or location, data obtained over somewhat similar geographical areas are in reasonable agreement with the OSO-I measurements.

The values of earth radiation obtained from the OSO-I data ranged from 92 to 112 Btu/hr ft^2. Tiros III measurements over the tropical Atlantic Ocean, in the same general area as the OSO data, showed a value of 90 Btu/hr ft^2. The latitudinal averages of earth radiation obtained from Tiros IV, for approximately the same latitudes as the OSO measurements, ranged from 74 to 84 Btu/hr ft^2.

Measurements of local albedo from OSO-I gave values from 10 to 38 percent. As might be expected, these values are larger than the Tiros III results of approximately 9 percent, which were obtained from a radiometer having a more limited field of view than that on OSO and which viewed clear skies and ocean areas. The Tiros IV latitudinal averages for the geographical areas of interest ranged from 25 to 34 percent.

An uncertainty analysis which was applied to the OSO-I data illustrates the difficulties involved in making accurate radiometric measurements. The principal problem is that a great many variables are involved in the measurements, each one contributing a possible error. Large uncertainties, therefore, can result. The results of this analysis strongly suggest the need for the inclusion of uncertainty analyses in the reporting of radiometric data. If the numerical results of the analysis are representative of the order of magnitude of error generally associated with measurements of this type, close agreement between the results of any two investigators may be somewhat fortuitous.

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TABLE I

UNCERTAINTY VALUES ASSIGNED TO VARIABLES USED FOR DETERMINING EARTH RADIATION

Variable	Uncertainty of Variable
T	$\pm 3°R$
$dT/d\theta$	$\pm 20°R/hr$
T_c	$\pm 3°R$
ϵ	± 0.05
A	$\pm 0.01 A$
wc	$\pm 0.05 wc$
K	$\pm 0.05 K$
F_E	$\pm 0.02 F_E$

TABLE II

UNCERTAINTY VALUES ASSIGNED TO VARIABLES USED FOR DETERMINING ALBEDO

Variable	Uncertainty of Variable
T	$\pm 2°R$
$dT/d\theta$	$\pm 15°R/hr$
T_c	$\pm 2°R$
α_s/ϵ	± 0.04
α_s	± 0.03
A	$\pm 0.01 A$
S	± 0.025
E	$\pm 10\ Btu/hr\,ft^2$
wc	$\pm 0.05 wc$
K	$\pm 0.05 K$
F_S	$\pm 0.01 F_S$
F_E	$\pm 0.02 F_E$
F_A	$\pm 0.05 F_A$

A-31208-12

DESIGN OF RADIATION SENSORS

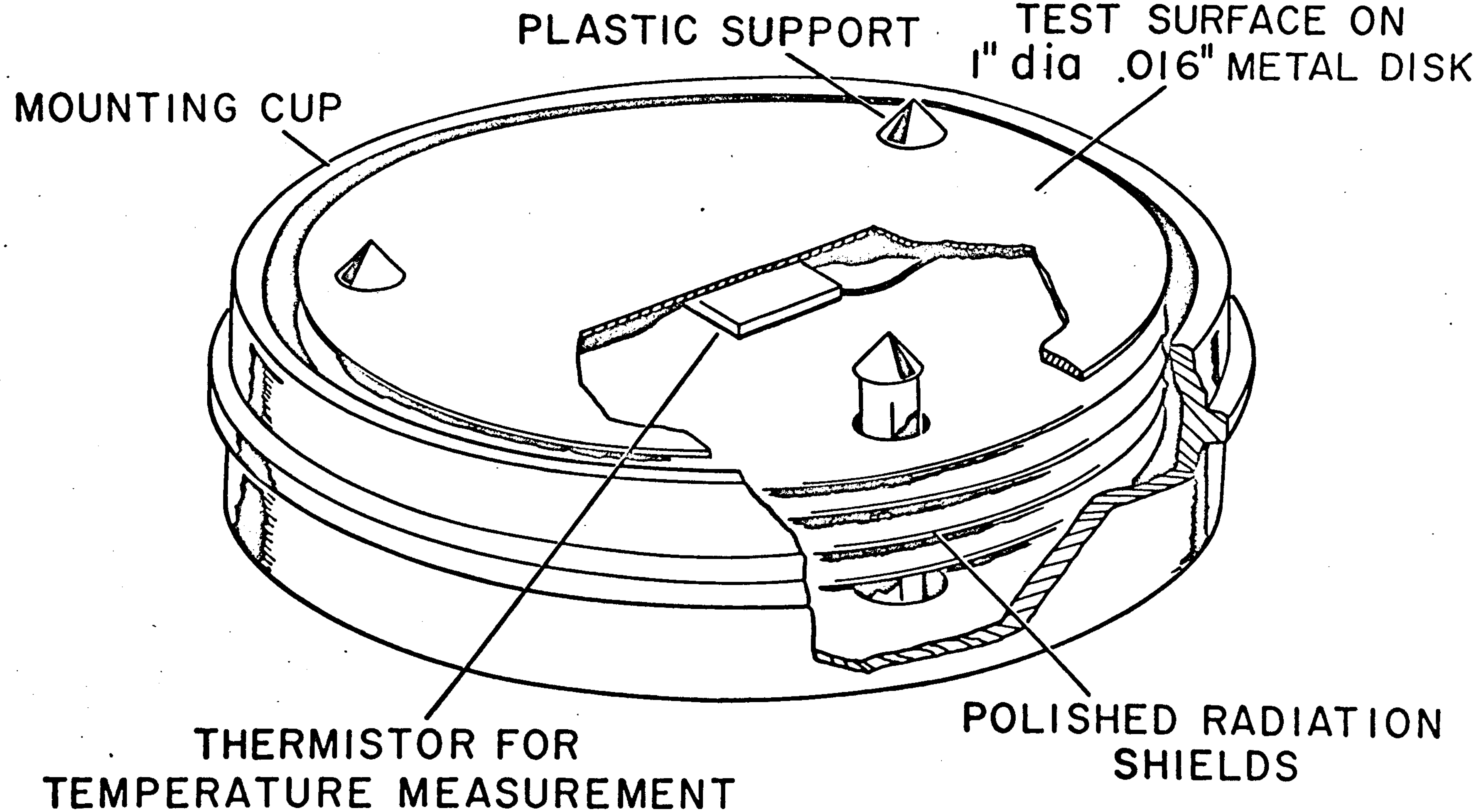

Figure 1
Design of Radiation Sensors

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MOUNTING OF RADIATION SENSORS

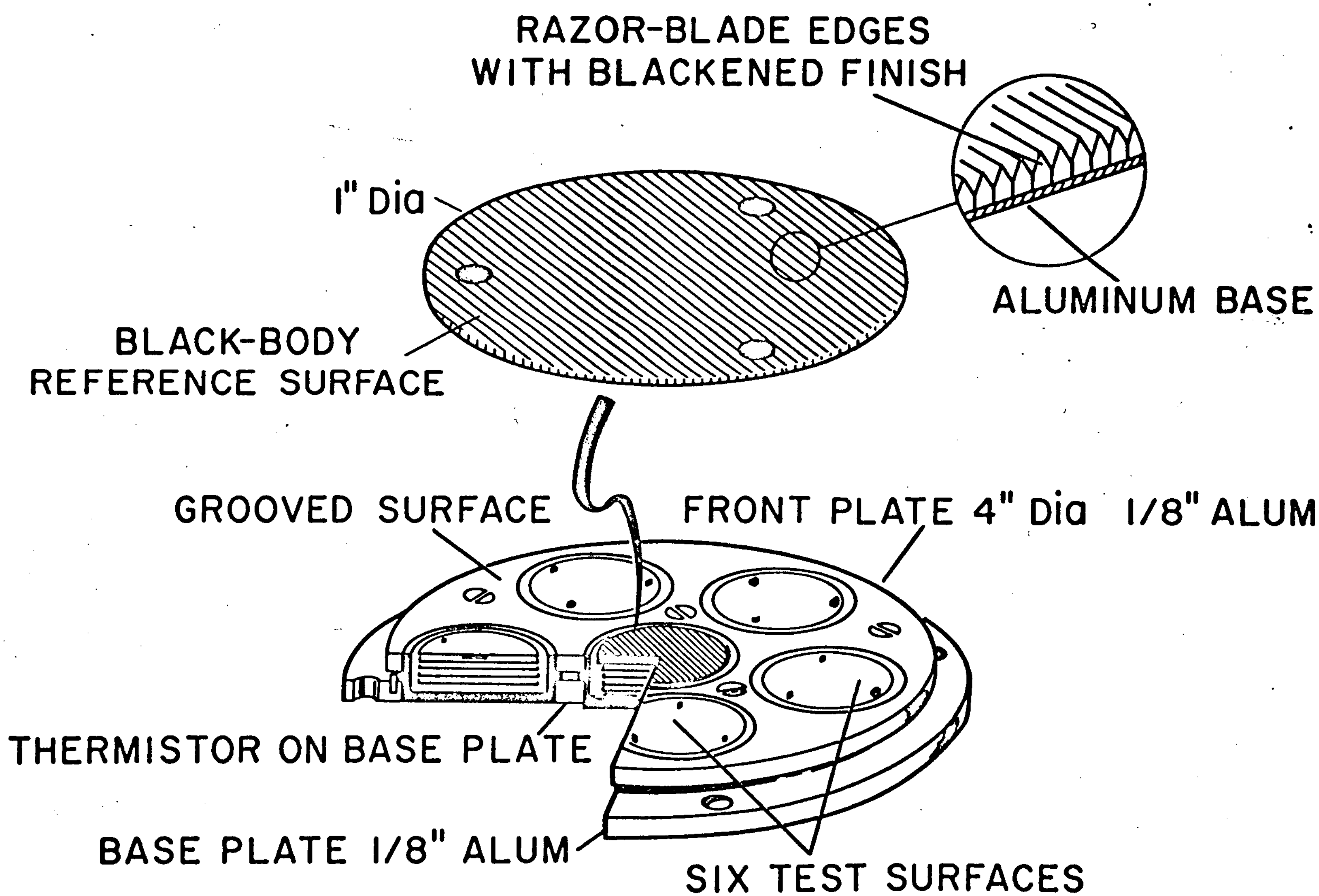

Figure 2
Construction of Razor-Blade Reference, and Mounting of Sensors

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AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA

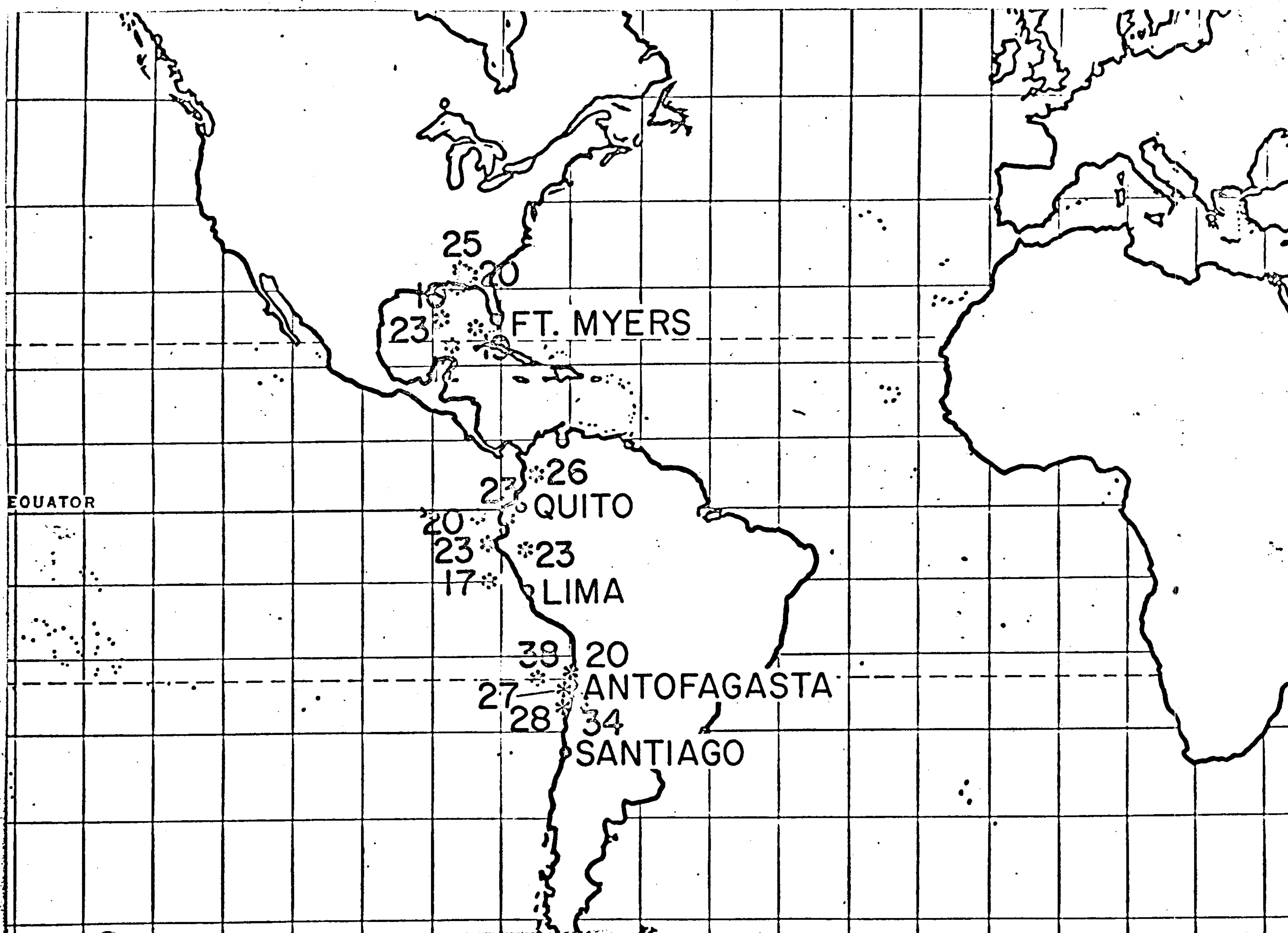

Figure 1
Albedo Values Deduced from OSO Experimental Data
(Values Designated in Percent)

A-28990-11

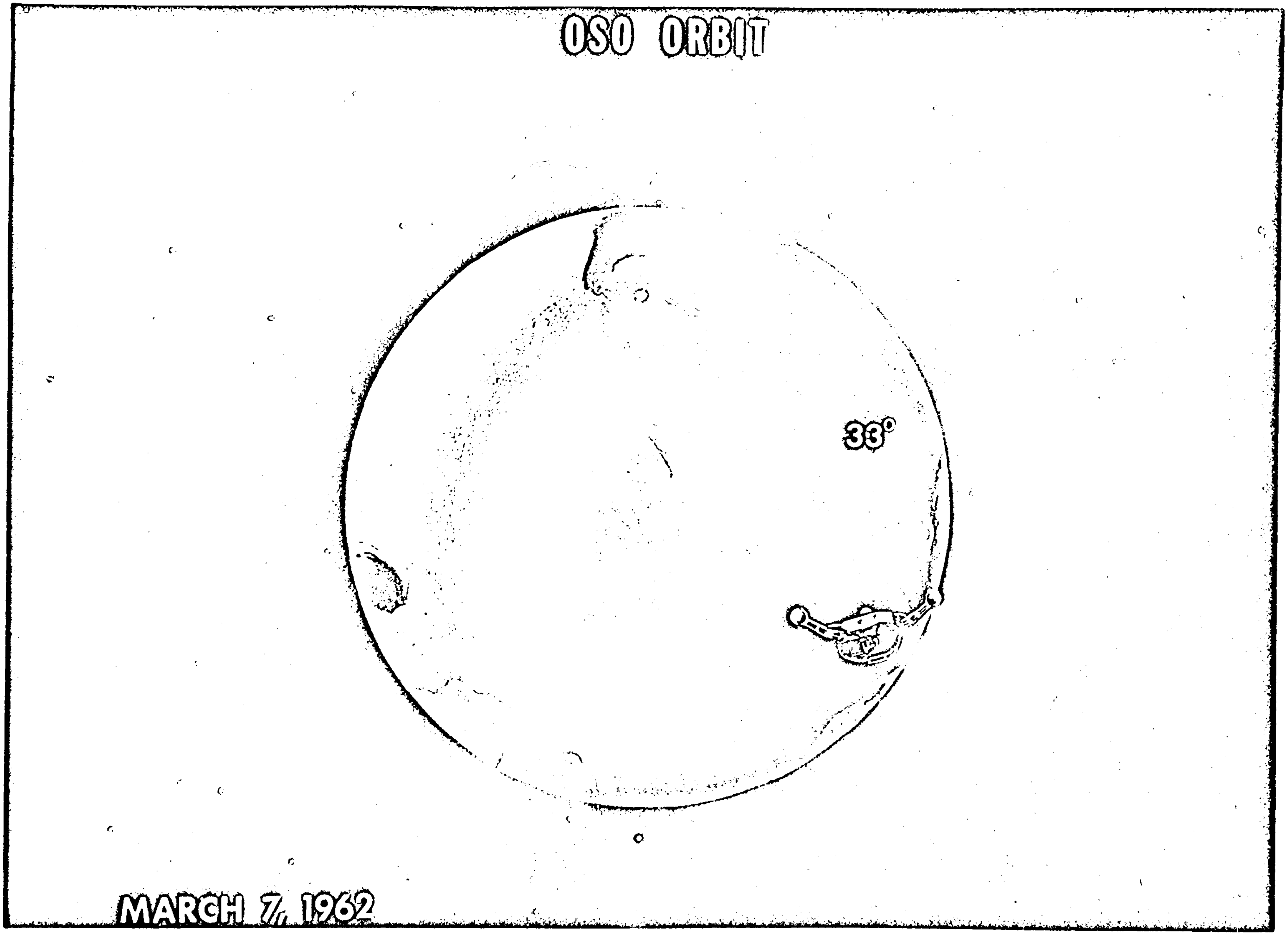

Figure 3
Orbit of First Orbiting Solar Observatory

A-28990-15

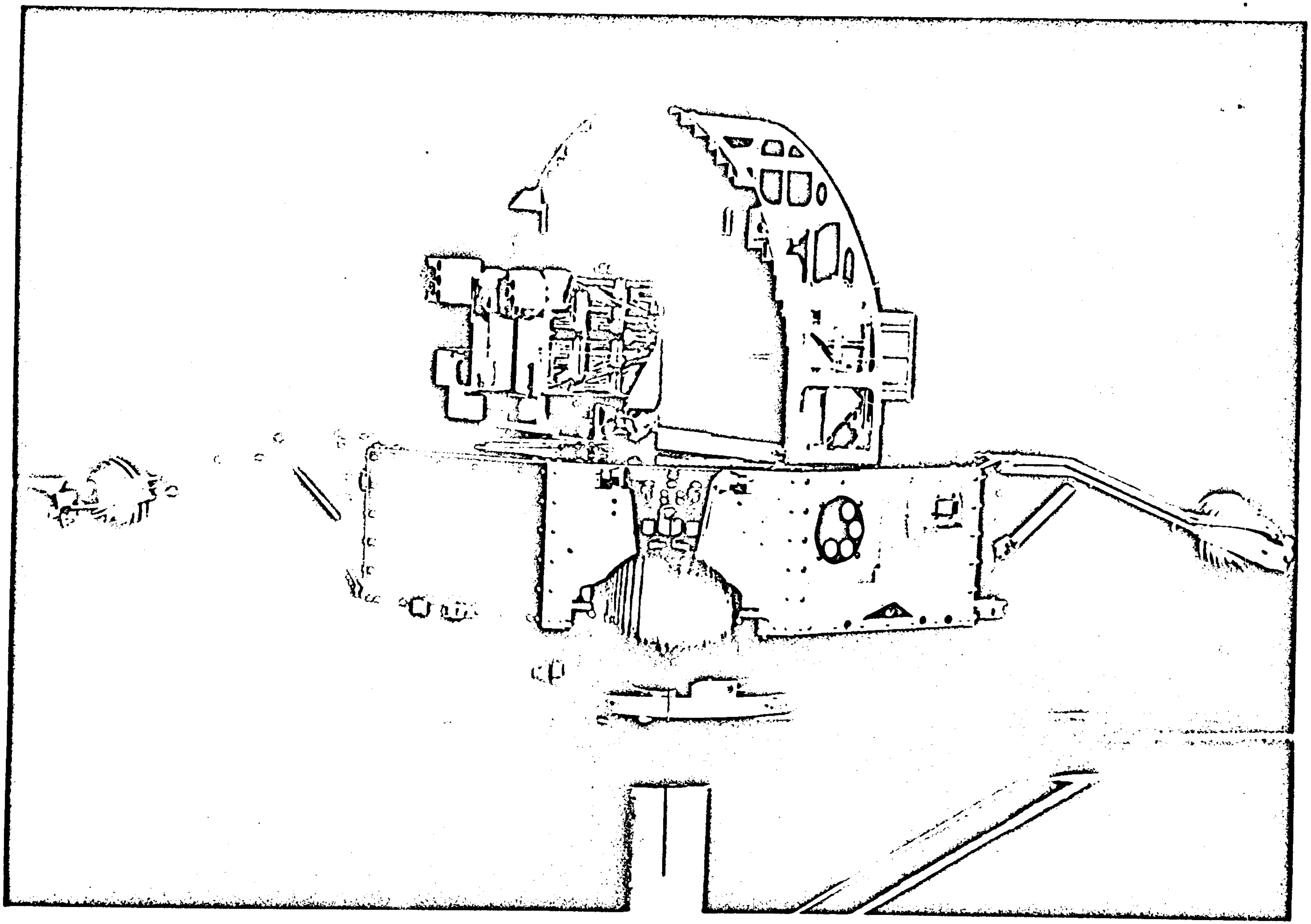

Figure 4
Orbiting Solar Observatory with Sensor Plate
Installed on Rim Panel

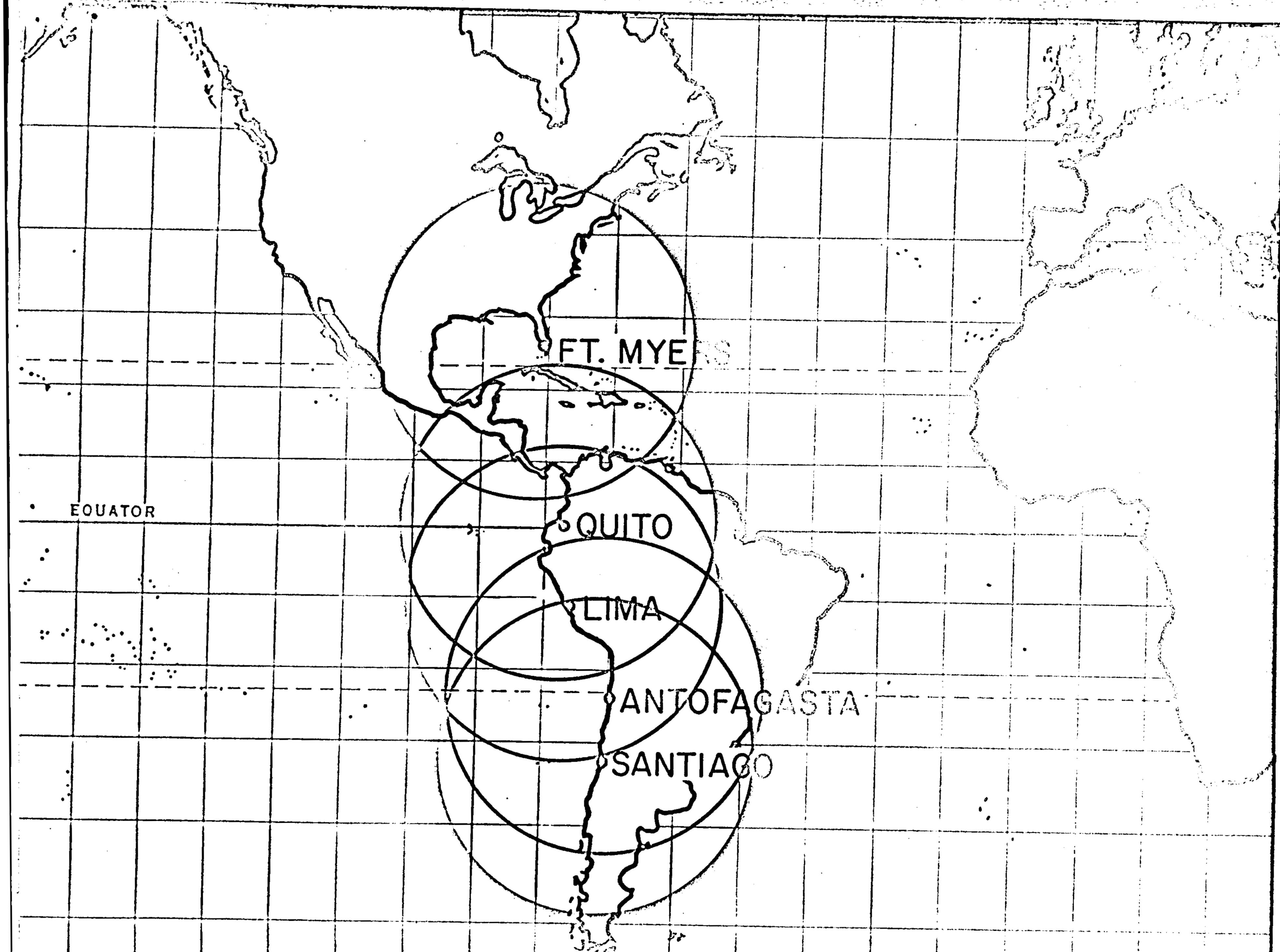

Figure 5
Geographical Areas Viewed by Satellite
When over the Minitrack Stations

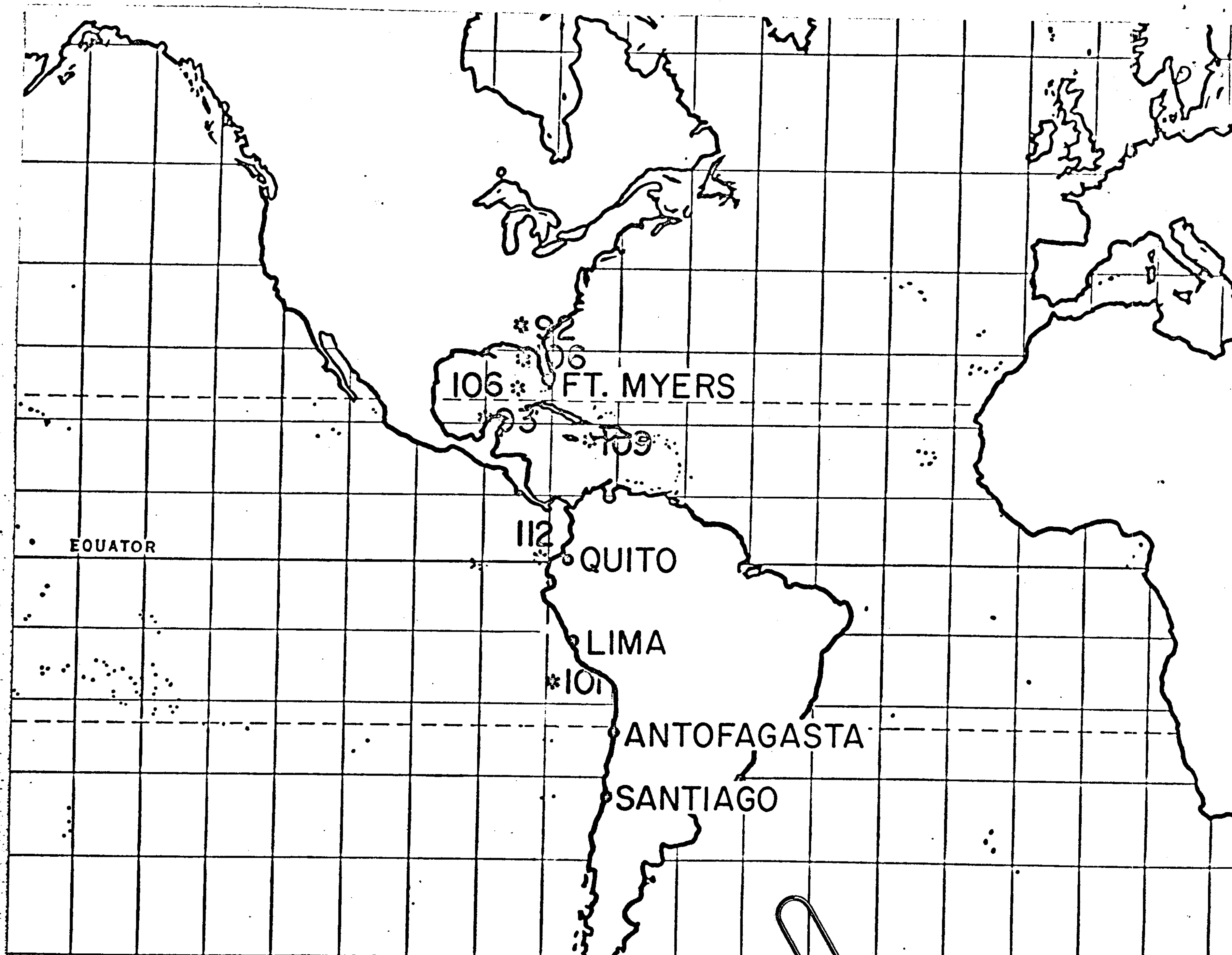

Figure 6
Earth Radiation Values Deduced From OSO Experimental Data (Values Designated in Btu/hr-ft²)